NASA Contractor Report 178399

THE DESIGN AND PRELIMINARY CALIBRATION
OF A BOUNDARY-LAYER FLOW CHANNEL

(NASA-CR-178399) THE DESIGN AND PRELIMINARY CALIBRATION OF A BOUNDARY-LAYER FLOW CHANNEL (Vigyan Research Associates) 37 p CSCL 01A
N88-12457
Unclas
G3/02 0106527

Dhanvada M. Rao and Timmy T. Kariya

VIGYAN RESEARCH ASSOCIATES, INC.
Hampton, Virginia

and

GEORGE WASHINGTON UNIVERSITY
Langley Research Center
Hampton, Virginia

Contract NAS1-17919
Cooperative Agreement NCC1-24
October 1987

NASA

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

ABSTRACT

The design procedures and characteristics of a low-speed flow research channel are described. The channel is an open-circuit wind tunnel for the study of two-dimensional turbulent boundary-layers under controlled pressure gradients, and follows design guide-lines from published literature on blower tunnels incorporating wide-angle diffusers. An unconventional 'radial-splitter' type of wide-angle diffuser was employed, and a streamtube computer code (General Electrical Streamtube Curvature Code) was used to check the design of the contractions. Two alternate test sections can be employed: a general-purpose 2 ft by 2 ft section and 0.5 ft by 2 ft boundary layer section, with fixed velocities of 25 and 90 fps respectively. Experimental techniques and data are prescribed for the evaluation of diffuser efficiency, boundary-layer test section characteristics, and the overall flow channel performance.

INTRODUCTION

When the kinetic energy of a fluid near the surface of a body has been reduced by friction, there arises a problem of maintaining flow in regions where the pressure is increasing in the flow direction. This inability or reduced ability of the flow to proceed into regions of rising pressure results in rapid boundary layer thickening and flow separation which degrades the efficiency and limits the performance of aerodynamic devices.

Prevention of boundary layer separation has been investigated extensively and a number of methods to achieve it have been proposed. Exploitation of natural turbulence, partial removal of the boundary layer by suction, energizing the boundary layer by tangential blowing through slots, or increasing the rate of mixing by auxiliary devices have all proven to be effective in varying degrees. Recently, there has been a renewal of interest in the use of surface vortex generators for separation control, and vortex generator designs aimed at improved efficiency are under investigation (refs. 1 and 2).

To allow systematic experimental studies of surface vortex generator mixing devices, a facility is required for simulating the encounter of a two-dimensional boundary layer with varying adverse pressure gradients. Survey of the available low-speed research facilities at NASA Langley Research Center indicated that their standard test section designs would require extensive modification in order to realize the desired flow conditions. Accordingly, a new boundary layer flow channel was designed and built for the purpose of providing greater flexibility of experimental arrangement for detailed study of vortex generator designs.

The objective of this special-purpose facility was to produce relatively thick turbulent boundary layers for enhanced flow visualization, more accurate profile data, and better turbulence information. Also, higher Reynolds numbers could be obtained by increasing the characteristic length instead of the reference velocity.

AERODYNAMIC DESIGN CONSIDERATIONS AND CONSTRAINTS

To simulate a two-dimensional boundary layer, a highly uniform swirl-free flow is desired. The spanwise and streamwise variation of the freestream velocity at a zero pressure gradient was specified to be $\pm$ 1%. For the proposed research on separation control of highly decelerated turbulent boundary layers, an exceptionally low turbulence intensity in the freestream was not considered a primary requirement.

The test section has a wide shallow rectangular cross-section with the floor boundary layer forming the test medium. The ceiling is of adjustable divergence such that the longitudinal freestream velocity gradient can be reduced to zero over the first half of the test-section length. The downstream half of the adjustable ceiling is used independently to create a controlled adverse pressure gradient sufficient to force separation of the floor boundary layer.

An orthodox approach to the flow channel design was considered along the lines of a blower-type wind tunnel consisting of a wide-angle diffuser, settling chamber, contraction and test section exhausting to the atmosphere (refs. 3 and 4).

Four major considerations had to be observed in the tunnel design: 1) limited space; 2) flexibility of test configuration; 3) economy; and 4) ease of construction. These are briefly discussed in the following.

The overall length of the tunnel as constrained by the available floor space was not to exceed 42 feet, including a boundary layer test section length of four feet.

A high degree of flexibility in the design to make the facility readily adaptable for a variety of research requirements was accorded high priority. Although initially intended for boundary layer studies initially, a two-stage contraction design was adopted in order to allow two different-sized test section for increased research utility of this facility.

The alternate test sections were selected to be a 2 ft by 2 ft general-purpose section and a 0.5 ft high by 2 ft wide boundary layer section. Accordingly, the two-piece contraction consisted of: an initial 9:1 contraction with a 2 ft by 2 ft exit, followed by a second 4:1 contraction leading to a 0.5 ft by 2 ft boundary layer channel. The overall contraction ratio of 36:1 could be expected to yield a highly uniform flow with low turbulence level in the boundary layer section. This contraction arrangement with the specified test section area led to a square settling chamber of 6 ft by 6 ft.

A tolerance of 1/16" on the internal surfaces was considered adequate in construction of the tunnel components upstream of the test sections. Pine was selected as the main construction material because of low cost and availability in a variety of sizes. Plywood was used to form the flow surfaces the tunnel, and with proper finishing provided a reasonably hard

smooth surface, relatively free of distortions.

COMPONENT DESIGN

The components of the tunnel are shown in figure 1. The room air enters the blower through filters which trap dust and fine debris. The blower output flows through a wide-angle diffuser into the settling chamber containing screens, passes through the contractions and test section and exits into the surrounding room.

BLOWER - The centrifugal blower is powered by a 7 1/2 HP electric motor and produces an output of 6000 cfm of air at 3 inches of water. The blower is mounted on a steel frame which sits on vibration damping pads. Speed control is possible in steps by changing pulleys between the motor and the impeller.

TRANSITION PIECES AND DIFFUSER - Space limitations required every tunnel section to be of a minimum length. The diffuser design needed particular attention, since it usually occupies a major portion of the tunnel length.

An orthodox, straight wall long diffuser was initially considered. The maximum diffuser angle, 2θ, for a 2-D channel for which unidirectional, self-preserving, fully developed flow is possible without any form of boundary layer control is 4.3 degrees (ref. 5). For an area ratio of 18 assumed for this tunnel, a conventional diffuser would be approximately 27 feet in length, an obviously impractical dimension. Therefore, alternative diffuser arrangements were considered.

A considerable amount of data on successful wide angle diffuser designs has been compiled by Mehta (ref. 3). However, many of these designs were

unsuited to the large diffuser ratio required here, and active-control type designs such as trapped vortex, rotating cylinder and wall suction were excluded because of their attendant complexity. The two designs eventually chosen for serious review were: wide angle diffuser with screens and the ´radial-splitter´ diffuser.

Resistance screens placed in a diffuser assist in spreading the flow to provide a more uniform velocity distribution (a detailed description of this technique is given by Dryden and Schubauer, ref. 6). However, placement of screens across the flow also produces a substantial pressure loss. While this penalty may be acceptable in many cases, the upstream energy loss has to be kept low for a blower tunnel such as the present one, which is subject to a considerable kinetic energy loss when discharging the flow at its maximum speed (i.e., without employing an exit diffuser)..

The use of radial splitters in wide-angle diffusers, which operate by deliberate and controlled flow separation for rapid spreading, were extensively tested by Raju and Rao (refs. 7 and 8) and Rao and Sheshadri (ref. 9). The conical diffuser is segmented into eight, triangular expanding passages. With an uniform (or axisymmetric) inlet velocity profile, each passage captures an equal part of the total volume flow. The inner 45 deg. corners between adjacent splitters cause a relatively rapid growth of the boundary layer. The adverse pressure gradient causes the low-energy corner flow to separate and form a long bubble extending to the diffuser exit plane. The displacement effect of the separation bubble spreads out the incoming flow, and then fill up the passages due to intense mixing. A small trip placed on the entrance apex of the radial splitters is sufficient to trigger

and sustain this controlled separation mechanism. The exit flow uniformity depends on the bubble length, which can be controlled by varying the separation trip size.

Using an equivalent diffuser angle, 2θ, of 15 degrees for each individual triangular passage (see Rao refs. 10 and 11), an overall length of 5.574 feet was calculated for the diffuser. This is a considerable improvement over the conventional diffuser designed for attached flow, and also provides a reasonable pressure recovery performance (unlike with screens). The overall diffuser angle was calculated to be 41 degrees.

The radial splitter diffuser required a geometry that was symmetric through the cross-section of the air flow and approximated a circular shape. An octagonal cross-section was chosen for the diffuser since it was simpler to construct than a circular cone. Transition pieces are provided between the rectangular blower exit and the octagonal diffuser entry, and also at the diffuser exit connecting to the square settling chamber. The resulting total diffusion length was 10.574 feet; details of the cross-section design are shown in figure 2.

SETTLING CHAMBER - The settling chamber is a rectangular box with an internal cross-section of 6 ft by 6 ft and a length of 44 inches. The chamber was designed as a pressurized box with load bearing wooden beams and a plywood skin mounted from inside and carefully sealed.

Three turbulence-damping screens are provided in the settling chamber. A honeycomb system is normally employed before the screens to remove swirl and lateral velocity variations (ref. 12). However, since the radial splitters would inhibit any large-scale swirl emerging from the diffuser, it was decided

to dispense with a honeycomb in the interest of economy.

Literature survey on the effectiveness of screens (refs. 13 - 17) led to the choice of polyester screens with an open-area ratio, β, of 0.61 and a pressure drop coefficient, K, of 1.1.

To maximize the screen effectiveness, it is important to allow for enough gap between screens for turbulent mixing and dissipation. Using experimental results from various sources (refs. 3, 18 and 19), the minimum distance between screens was calculated to be approximately 8.5 inches, and the optimum distance to the contraction entrance to be 13.75 inches. The actual screen placement is shown in figure 3.

Provisions were made so that the screens could be removed easily from the tunnel for periodic maintenance and cleaning.

PRIMARY AND SECONDARY CONTRACTIONS - The prediction of turbulent intensity reduction through a contraction is largely based on the contraction ratio (ref. 13). The primary contraction ratio of this tunnel was 9:1 which can reduce axial turbulence intensity of the mean flow by approximately 75%.

The design of the primary contraction (i.e. cross-sectional area distribution) was adapted from the NASA Langley Research Center 4 X 7 Meter Wind Tunnel. The 4 x 7 tunnel contraction contours were modified to obtain a 9:1 ratio, starting with the 6 ft by 6 ft cross-sectional dimensions of the settling chamber. The effect of the design modification was checked for the possibilty of flow separation by a computer code known as the General Electric Streamtube Curvature Code (GESTC) (refs. 20 and 21).

The General Electric Streamtube Curvature code is a potential flow code that uses a streamtube curvature approach. The code incorporates a

compressible turbulent boundary layer solution which identifies the turbulent separation location through calculated pressure gradients for a given input contour. However, GESTC uses an axisymmetric input geometry format which slightly distorts the actual curvature.

Results from GESTC for the modified 4 X 7 contour indicated significant separation in the first inflection of the contour as can be seen in figure 4, diagram A. Therefore, the contour was suitably modified and re-checked by GESTC. After several design iterations (figure 4, diagrams B and C), a shape was eventually obtained that predicted only mild incipient separation at the contraction inlet (diagram D).

The secondary contraction, which is a 2-D contraction with a ratio of 4:1, was considered more critical with regards to the uniformity and steadiness of the airflow, and so more care was taken to avoid separation in this contraction.

The secondary contraction contour was generated using a computer code based on the solution of the 2-D Laplace equation proposed by Thwaites (ref. 22) for the velocity potential for a given velocity distribution along the centerline. The resulting contour was tested by GESTC and showed separation in the concave region of the curvature (see figure 5, diagram A). The contour was modified (figure 5, diagrams B and C) until results from GESTC predicted total elimination of separation in the contraction (diagram D).

Finally, the combination of primary and secondary contractions was checked by GESTC, and results were extremely satisfactory. Using the predictive methods of Batchelor (ref. 13), the total contraction ratio of 36:1 promised a reduction of almost 92% in the axial turbulence intensity of the

mean flow. The dimensions of the primary and secondary contractions are given in Table 1 and Table 2, respectively.

Each contraction was constructed of plywood skins attached to a wooden frame. In order to keep the contour construction within acceptable tolerance ($\pm$ 1/16 inch), the shapes of the contractions were first laid out on flanges, and the skins attached to the flanges. This method of construction was economical and produced quite accurate reproductions of the designed contours. Load bearing wooden beams were subsequently affixed to keep the maximum surface deformation of the skins to less than 1/32 inch.

TEST SECTION - The four foot long test section has a constant width of 24 inches and an initial height of 6 inches. The entire test section was built of plexiglass and framed with oak beams. The plexiglass provided a flat and smooth surface and was ideal for flow visualization.

The top of the test section was hinged at the front end and halfway downstream (24 inches) from the test section entrance (see figure 6). The first part of the hinged roof was adjusted to compensate for the boundary layer growth in the test section and provide a zero pressure gradient in the flow direction, while the second part was tilted to create an adverse pressure gradient along the bottom surface. The shape of the pressure distribution was required to simulate the pressure recovery region on the upper surface of high-performance airfoils, i.e. a rapid initial pressure rise with a relaxing gradient in the flow direction.

PRELIMINARY TESTING

The preliminary evaluation of the tunnel focused on diffuser effectiveness. Diffuser performance is rated by two criteria: flow spreading action and pressure recovery. In the present instance, the flow spreading action was considered more important than pressure recovery, because it influences the test section flow quality.

Evaluation of the diffuser consisted of flow surveys using polyester tufts. Tufts were strung across the exit of the diffuser in the middle plane of each triangular passage to observe the uniformity of the emerging flow and detect any signs of flow reversal.

The diffuser was first tested without a separation trip at the splitter apex. In this case, the tufts indicated unequal flow capture in the different passages and also primarily a center-jet type velocity profile. The tufts nearest the diffuser centerline showed downstream flow while tufts near the inner walls showed reverse flow. The tufts in the upper cells streamed more strongly than the tufts in the lower cells. The unequal mass flow in the cells appeared to result mainly from the skewed velocity profile emerging from the centrifugal blower.

From the data presented in reference 11, the minimum disc diameter to force separation in the inner corners of the triangular passages was estimated as 9 inches diameter. A disc fabricated out of 3/4 inch plywood was attached to the diffuser inlet. This resulted in emergent flow from all passages, except very near the diffuser walls. However, uneven flow capturing was still evident. In an effort to equalize the flow in all the cells, the trip disc was offset upwards until a more uniform exit flow was obtained from all the

passages.

A tuft survey was also performed on the centerline of the contraction surfaces from the last screen to the outlet of the secondary contraction. There was evidence of some regions of separation on the concave portion near the primary contraction inlet; however, the flow later reattached to the primary contraction surface and then remained attached up to the contraction exit.

DATA COLLECTION

Data measurement for flow evaluation was based on a Scanivalve pressure sensor with 48 ports connected to the test section taps, measuring pressure via an 1 psid pressure transducer. A Hewlett Packard computer, data acquisition unit, and software were used to accomplish data processing and control of the Scanivalve.

The primary interest in flow evaluation was to demonstrate uniformity of tunnel flow. A total pressure rake was fabricated to span the vertical plane of the test section. The rake was placed at various horizontal spanwise stations to measure the velocity distributions.

To measure the longitudinal pressure distribution in the test section, pressure taps were provided at close intervals along the centerline (see figure 7). Pressure distribution measured along this row of taps was used to guide the determination of the top wall divergence angle for a zero pressure gradient along the test section length.

FLOW EVALUATION

A preliminary flow evaluation of the channel was conducted at the exit of the secondary contraction. Vertical distributions of the total pressure were obtained at various horizontal spanwise stations, and as a check for two-dimensionality, horizontal distributions were taken at fixed heights from the bottom. The pitot rake was aligned across the contraction exit as shown by figures 8 and 9.

Figures 10 and 11 illustrate the uniformity of the flow at the secondary contraction exit. There is very little deviation of the velocity distributions from the mean velocity of 89 ft/sec. The velocity variation is within $\pm$ 1% deviations from the mean velocity.

The velocity plots also indicate a boundary layer thickness of less than 0.25 inch at the contraction exit. Inspection of the velocity distributions near the corners of the tunnel ($Y = \pm 3$ inches, $Z = \pm 12$ inches) shows that the corner effects are not severe at this point in the flow channel.

The flow was then evaluated at the test section exit with a parallel channel configuration. Figure 12 at positon $Z = 0.0$ compares the vertical velocity distributions at contraction exit centerline to test section exit. The core flow is found to have accelerated to 91 ft/sec and is not as uniform as at the contraction exit, as expected due to the boundary layer growth in a parallel channel. However, further study of figures 12 and 13 indicate that the velocity distributions are still moderately uniform. A thicker boundary layer is indicated at the test section exit, as seen in figures 12 and 13. A boundary layer of approximately 0.75 inch has grown on all four wall of the test section, and severe corner effects are evident.

The test section ceiling was then diverged to correct for boundary layer growth. The longitudinal pressure plots in figure 14 show the typical pressure distributions obtained by adjusting the roof slope; a slope of 0.52 degrees was found to give a zero pressure gradient.

Finally, the flow was evaluated at the test secton exit with the correction for boundary layer growth. Figure 15 at position Z = 0.0 shows that the adjustment to zero pressure gradient has compensated for the growth of the boundary layer. The velocity of the freestream is constant in the streamwise and spanwise direction. The overall examination of figures 15 and 16 indicate that the flow is highly uniform through the cross-section of the boundary layer channel.

There is a significant amount of boundary layer growth as shown by the velocity plots. A viscous layer of almost 1 inch thickness has developed. Also, the corner effects are not very severe in comparison with the parallel channel configuration.

SUMMARY AND CONCLUSIONS

The flow channel provides a mean flow of high uniformity suitable for the proposed boundary layer vortex generator research. Though the present flow evaluation results must be considered preliminary, the tunnel design and construction appear to be quiite satisfactory. The adjustable test section provides an effective means of creating adverse pressure gradients as well as for compensating for boundary layer growth to start with a zero gradient flow. Future evaluation of the flow will include measurements of the turbulence intensity and the boundary layer profile in the test section.

The radial splitter diffuser proved to be effective in flow spreading over a very large area ratio. The resulting flow from the tunnel reaches the design velocity and is very uniform.

REFERENCES

1. Kuethe, A. M., "Boundary Layer Control of Flow Separation and Heat Exchange," United States Patent No. 3578264, 1968.

2. Kuethe, A. M., "Boundary Layer Control of Flow Separation and Heat Exchange," United States Patent No. 3741285, 1973.

3. Mehta, R. D., "The Aerodynamic Design of Blower Tunnels with Wide Angle Diffusers," Progress in Aeronautical Sciences, Vol. 18, Pergamon Press, 1977.

4. Bradshaw, P. and Pankhurst, R. C., "The Design of Low-Speed Wind Tunnels," Progress in Aeronautical Sciences, Vol. 5, pp. 1, MacMillan Co., 1964.

5. Townsend, A. A., "The Structure of Turbulent Shear Flow," Cambridge University Press, 1976.

6. Dryden, H. L. and Schubauer, G. B., "Use of Damping Screens for Reduction of Wind Tunnel Turbulence," Journal of Aeronautical Sciences, Vol.14, pp. 221, 1947.

7. Raju, K. N. and Rao, D. M., "Experiments on the Use of Screens and Splitters in a Wide Angle Diffuser," National Aeronautical Laboratory, Bangalore, TN-AE-24-64, April, 1964.

8. Raju, K. N. and Rao, D. M., "The Use of Splitters for Flow Control in Wide Angle Diffusers," National Aeronautical Laboratory, Bangalore, TN-AE-26-64, December, 1964.

9. Rao, D. M. and Sheshadri, S. N., "Application of Radial Splitters for Improved Wide Angle Diffuser Performance in a Blowdown Tunel," Journal of Aircraft, Vol. 13, pp. 538, 1976.

10. Rao, D. M., "Flow Stabilization in Large Area Ratio, Wide Angle Diffusers," Paper presented at CAARC, Specialist Meeting on Boundary Layers, Bangalore, Dec. 11-13, 1967.

11. Rao, D. M., "A Method of Flow Stabilization with High Pressure Recovery in Short Conical Diffusers," Aeronautical Journal of Royal Aeronautical Society, Vol. 75, pp. 336, 1971.

12. Loehrke, R. I. and Nagib, H. M., "Control of Freestream Turbulence by Means of Honeycombs: A Balance Between Suppresion and Generation," ASME Journal of Fluids Engineering, Vol. 98I, pp. 342, 1972.

13. Batchelor, G. K., "The Theory of Homogeneous Turbulence," The University Press, Cambridge, England, 1953.

14. Taylor, G. I. and Batchelor, G. K., "The Effect of Wire Gauze on Small Disturbance in a Uniform Stream," Quarterly Journal of Mechanics and Applied Mathematics, Vol. 2, pp. 1, Jan. 1949.

15. Morgan, P. G., "The Stability Of Flow Through Porous Screens," Journal of Royal Aeronautical Society, Vol. 64, pp. 359, 1960.

16. Bradshaw, P., "The Effect of Wind Tunnel Screens on Nominally Two-Dimensional Boundary Layers," Journal of Fluid Mechanics, Vol. 22, pp. 679, 1965.

17. Collar, A. R., "The Effect of a Gauze on the Velocity Distribuiton in a Uniform Duct," ARC R&M 1867, 1939.

18. Morel, T., "Comprehensive Design of Axisymmetric Wind Tunnel Contractions," ASME Journal of Fluids Engineering, Vol. 2I, pp. 225, 1975.

19. Laine, S. and Harjumaki, J., "Theoretical Study of Axisymmetric Contractions for Low-Speed Wind Tunnels," Helsinki University of Technology, Laboratory of Aeronautics, Report No. 75-A2, 1975.

20. Keith, J. S.; Ferguson, D. R.; Merkle, C. L.; Heck, P. H. and Lahti, D. J., "Analytical Method for Predicting Pressure Distribution About a Nacelle at Transonic Speeds," NASA CR-2217, 1973.

21. Ferguson, D. R. and Keith, J. S., "Modification of the Streamtube Curvature Program: Volume I - Program Modifications and User's Manual," NASA CR-132705, 1975.

22. Thwaites, B., "On the Design of Contraction for Wind Tunnels," ARC R&M 2278, 1946.

TABLE 1 - PRIMARY CONTRACTION COORDINATES

(Origin of axes at contraction entrance)

X (INCHES)	± Y, ±Z (INCHES)
0.0000	36.0000
2.0000	35.9100
4.0000	35.6256
6.0000	34.9620
8.0000	33.7980
10.0000	32.4828
12.0000	31.1724
14.0000	29.8204
16.0000	28.5816
18.0000	27.2940
20.0000	26.0064
22.0000	24.7200
24.0000	23.4444
26.0000	22.1820
28.0000	20.9292
30.0000	19.7064
32.0000	18.6156
34.0000	17.6424
36.0000	16.7664
38.0000	15.9888
40.0000	15.3288
42.0000	14.7864
44.0000	14.3544
46.0000	13.9716
48.0000	13.6320
50.0000	13.3536
52.0000	13.1256
54.0000	12.9120
56.0000	12.7236
58.0000	12.5724
60.0000	12.4416
62.0000	12.3240
64.0000	12.2292
66.0000	12.1596
68.0000	12.1008
70.0000	12.0528
72.0000	12.0192
74.0000	12.0012
75.0000	12.0000

TABLE 2 - SECONDARY CONTRACTION COORDINATES

(Origin of axes at contraction entrance)

X (INCHES)	$\pm$ Y (INCHES)
0.0000	12.0000
2.0000	11.9882
4.0000	11.9520
6.0000	11.8890
8.0000	11.7948
10.0000	11.6613
12.0000	11.4761
14.0000	11.2163
16.0000	10.8420
18.0000	10.2647
20.0000	9.3702
22.0000	8.4337
24.0000	7.5000
26.0000	6.5663
28.0000	5.6298
30.0000	4.7353
32.0000	4.1580
34.0000	3.7832
36.0000	3.5239
38.0000	3.3387
40.0000	3.2053
42.0000	3.1110
44.0000	3.0480
46.0000	3.0118
48.0000	3.0000

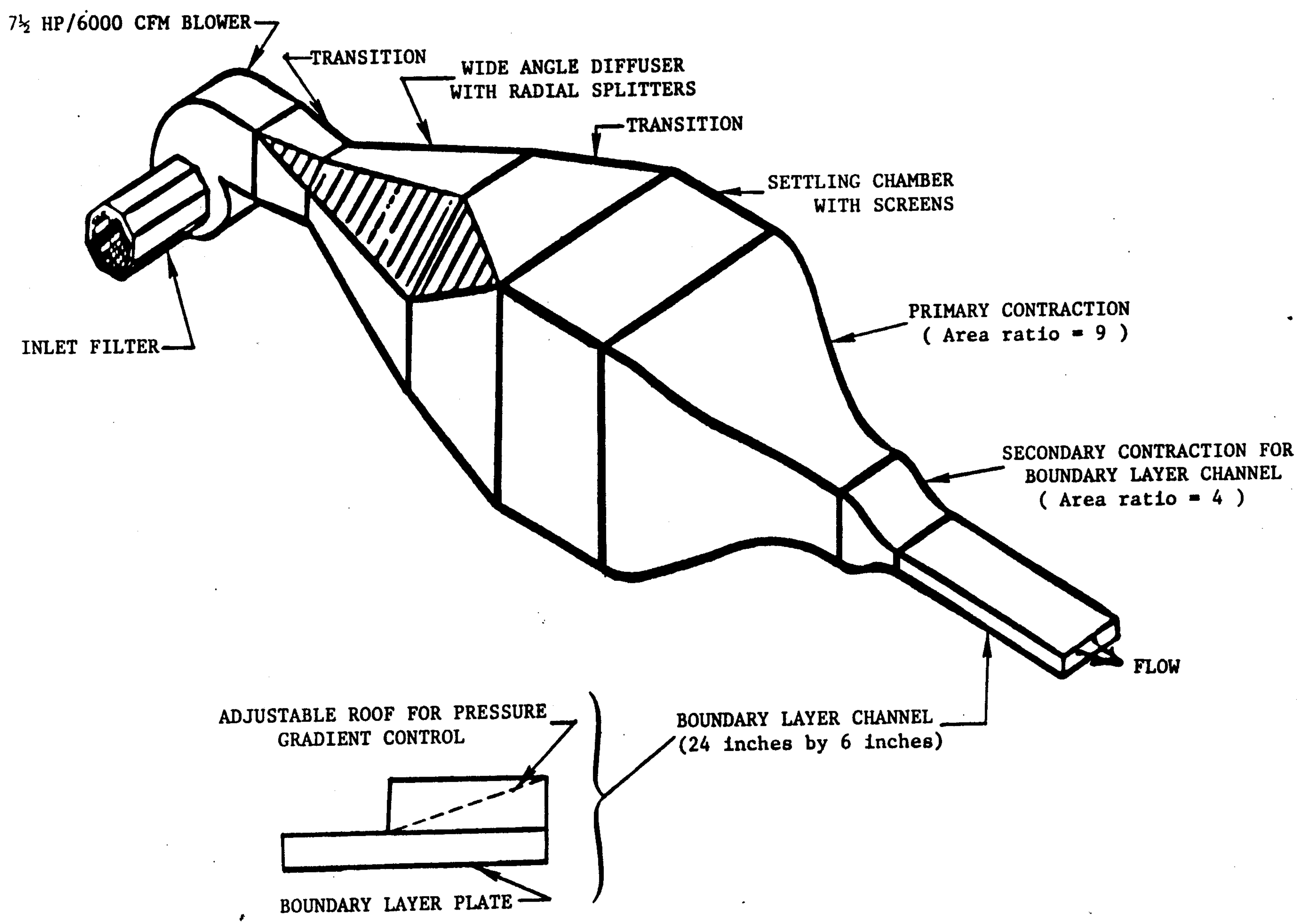


FIGURE 1 - LOW-SPEED BOUNDARY LAYER FLOW CHANNEL

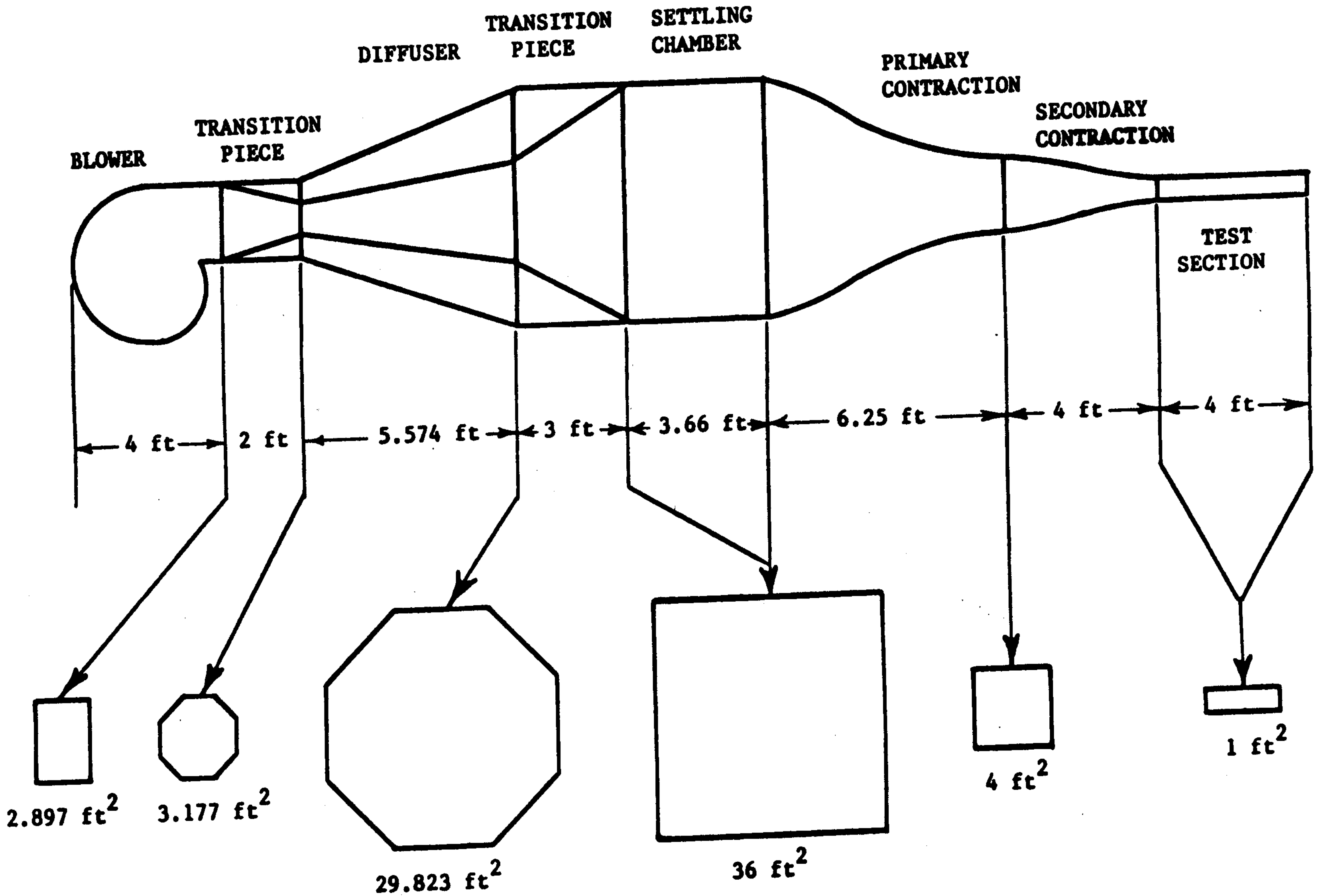


FIGURE 2 - CROSS-SECTIONS AND LENGTHS OF INDIVIDUAL COMPONENTS

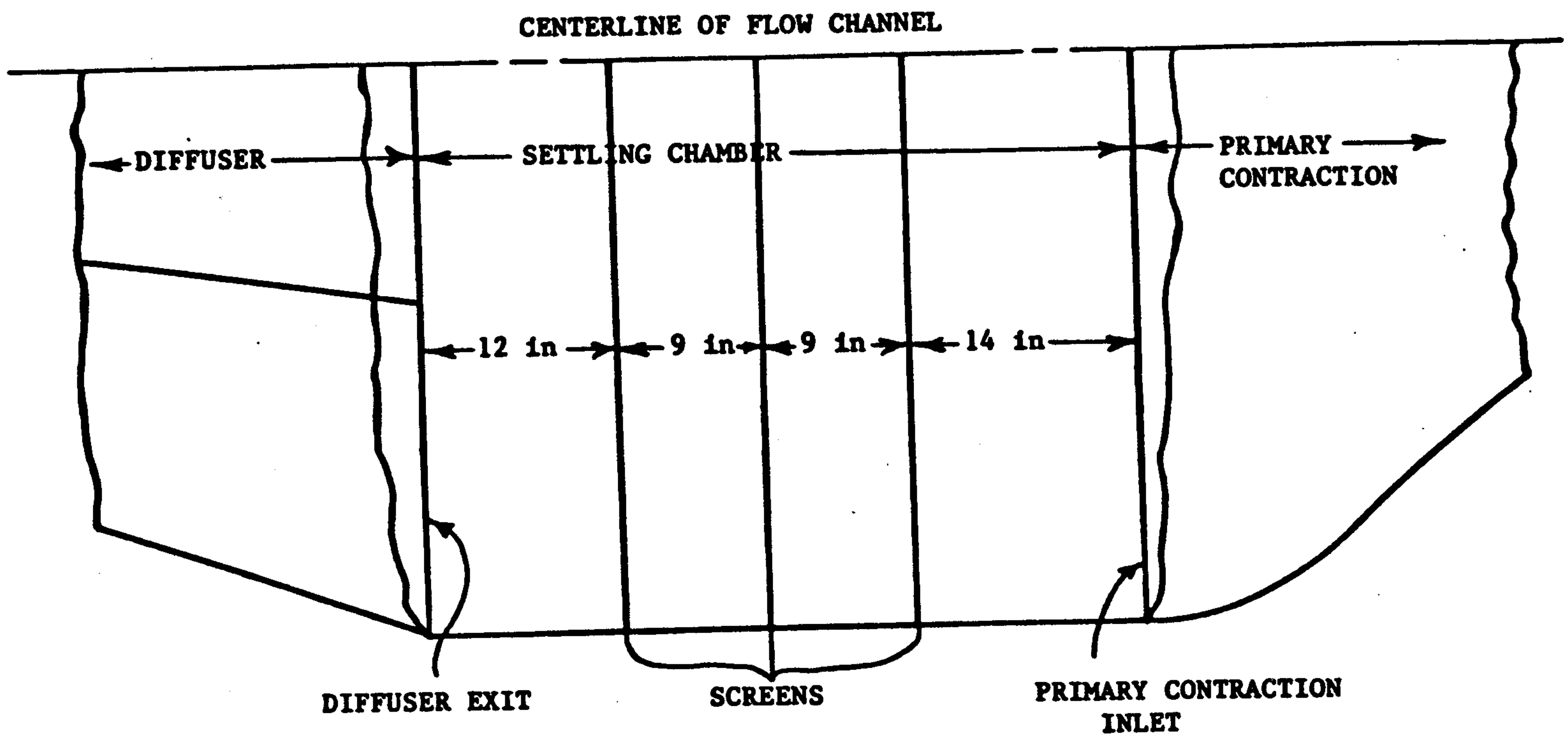


FIGURE 3 - SCREEN PLACEMENTS FOR FLOW MANAGEMENT WITHIN SETTLING CHAMBER

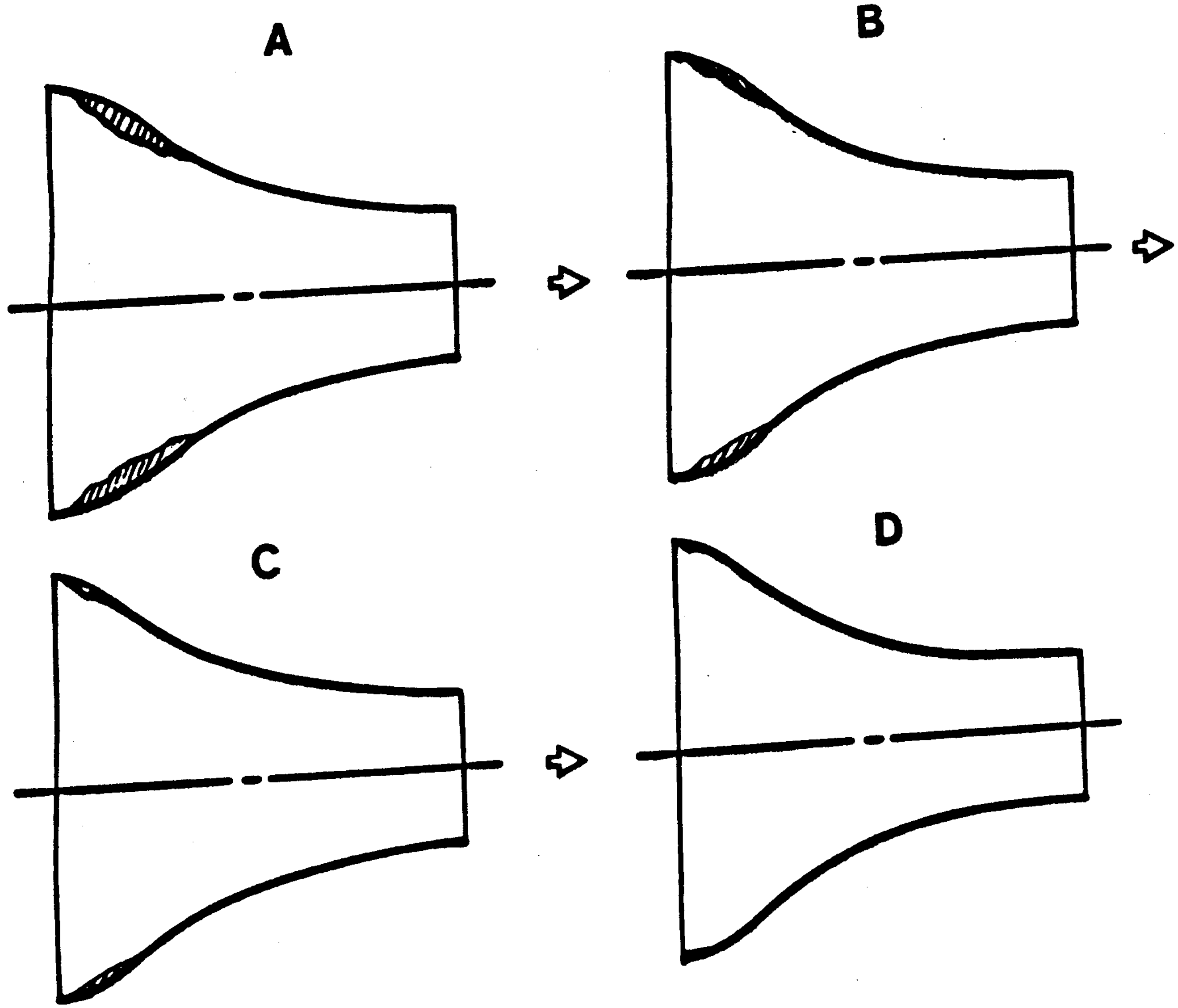


FIGURE 4 - RESULTS FROM GESTC FOR PRIMARY CONTRACTION

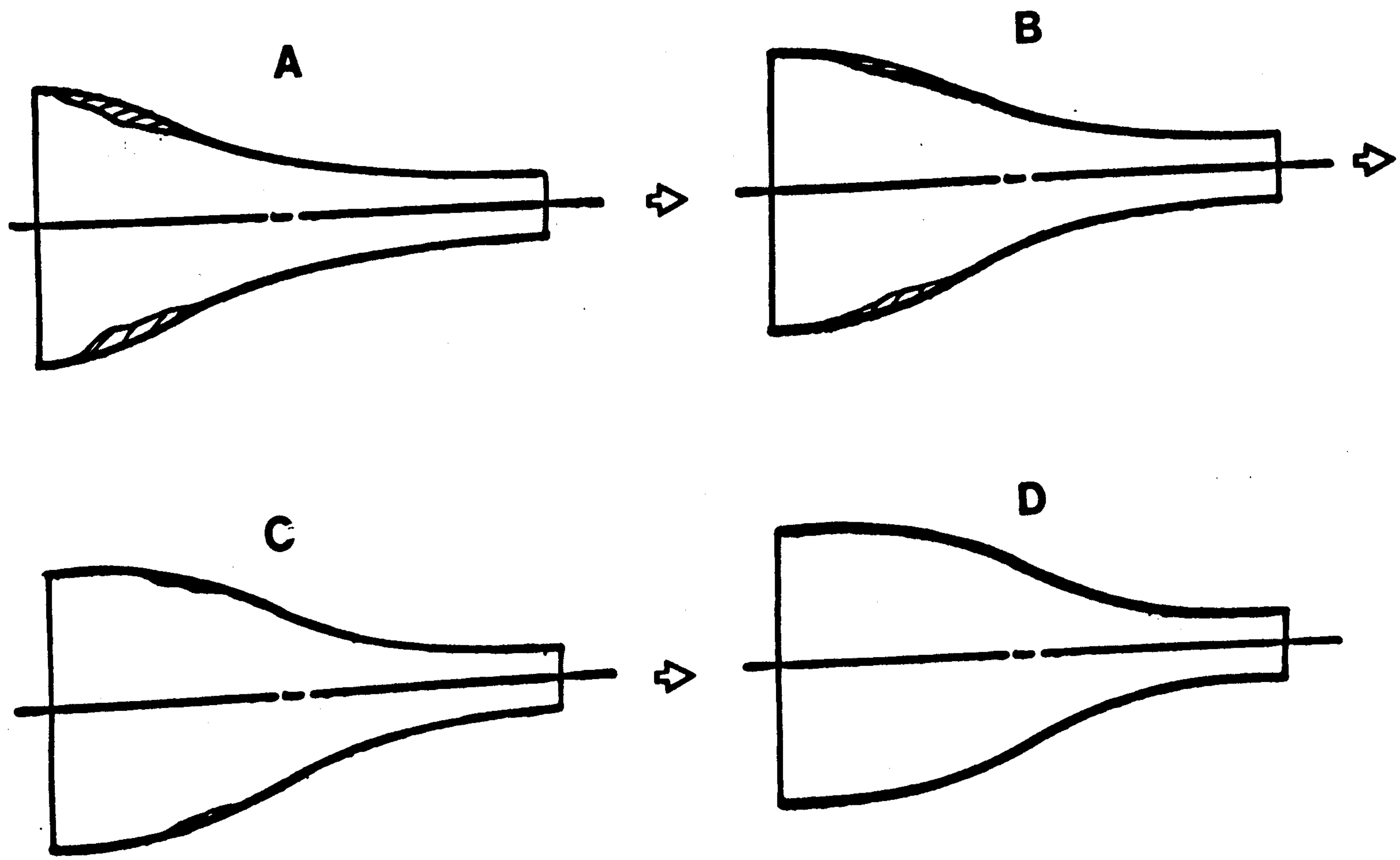


FIGURE 5 - RESULTS FROM GESTC FOR SECONDARY CONTRACTION

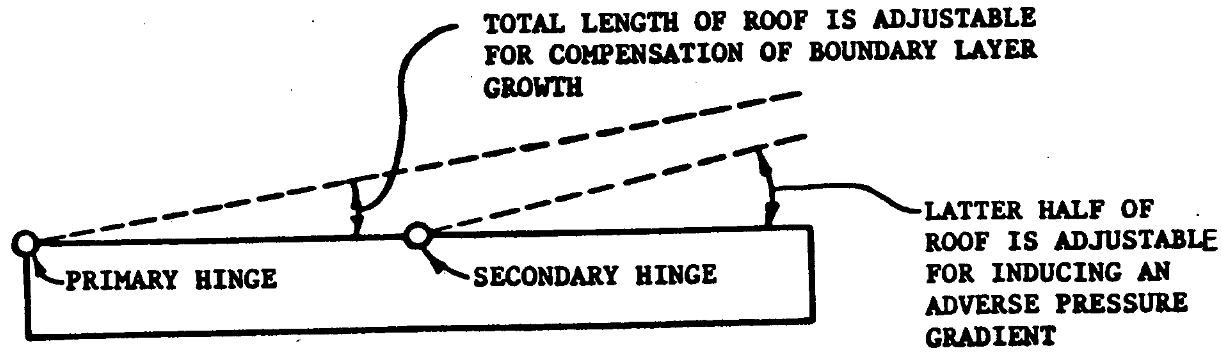
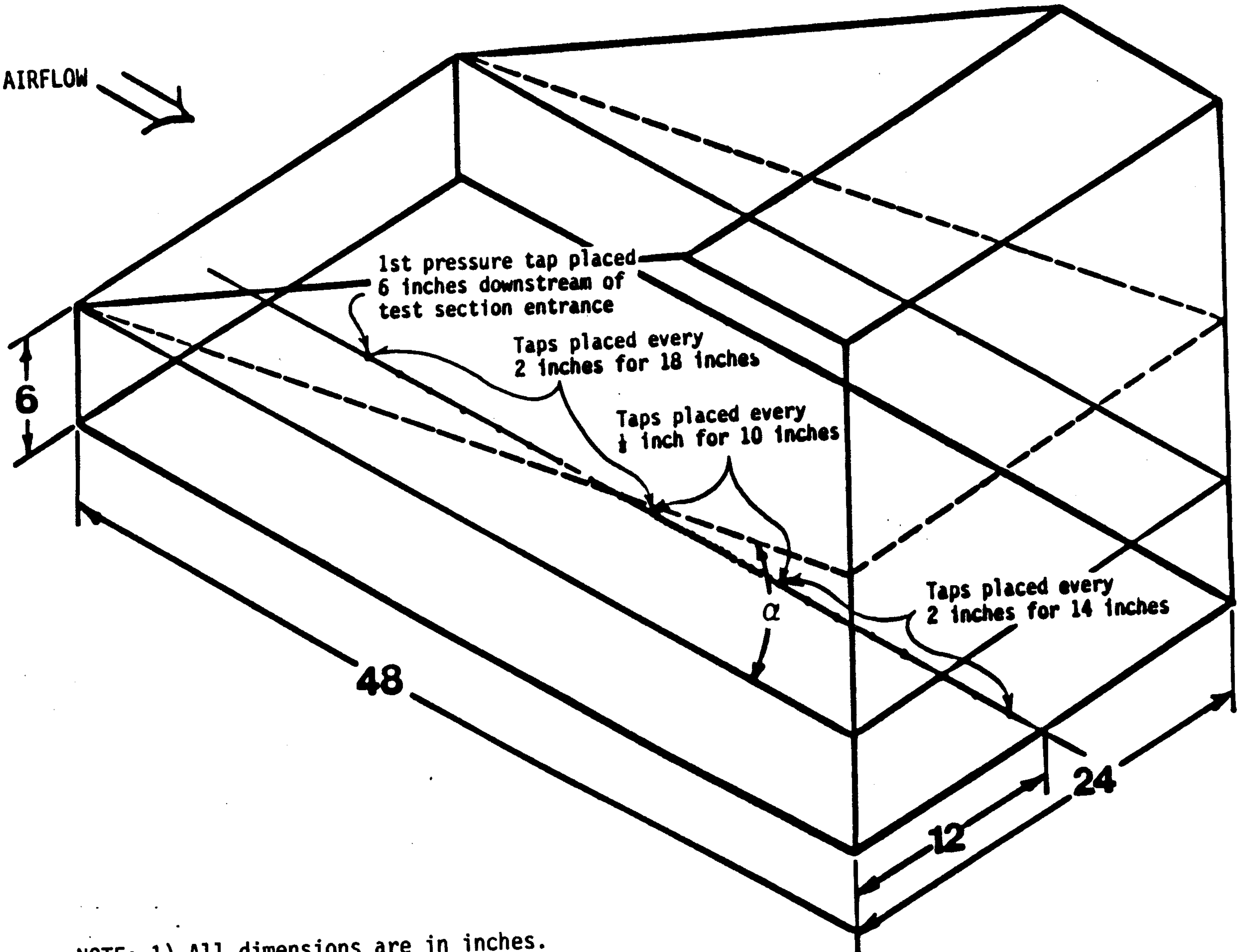


FIGURE 6 - DESIGN OF ADJUSTABLE ROOF FOR TEST SECTION



NOTE: 1) All dimensions are in inches.
2) α = Test section divergence angle.

FIGURE 7 - PLACEMENT OF LONGITUDINAL PRESSURE TAPS

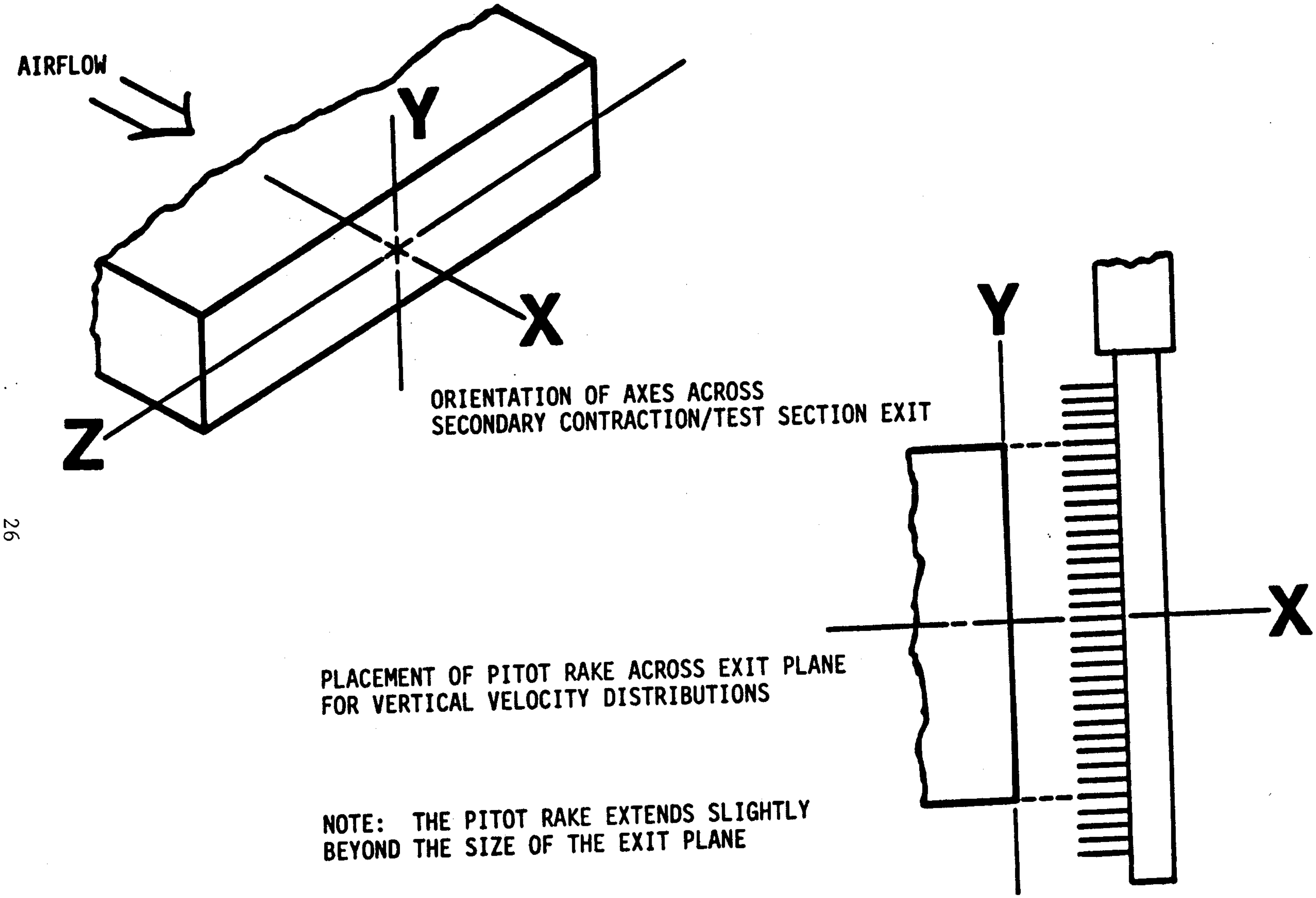


FIGURE 8 - PLACEMENT OF PITOT RAKE ACROSS EXIT OF SECONDARY CONTRACTION/TEST SECTION FOR ACQUISITION OF VERTICAL VELOCITY DISTRIBUTIONS

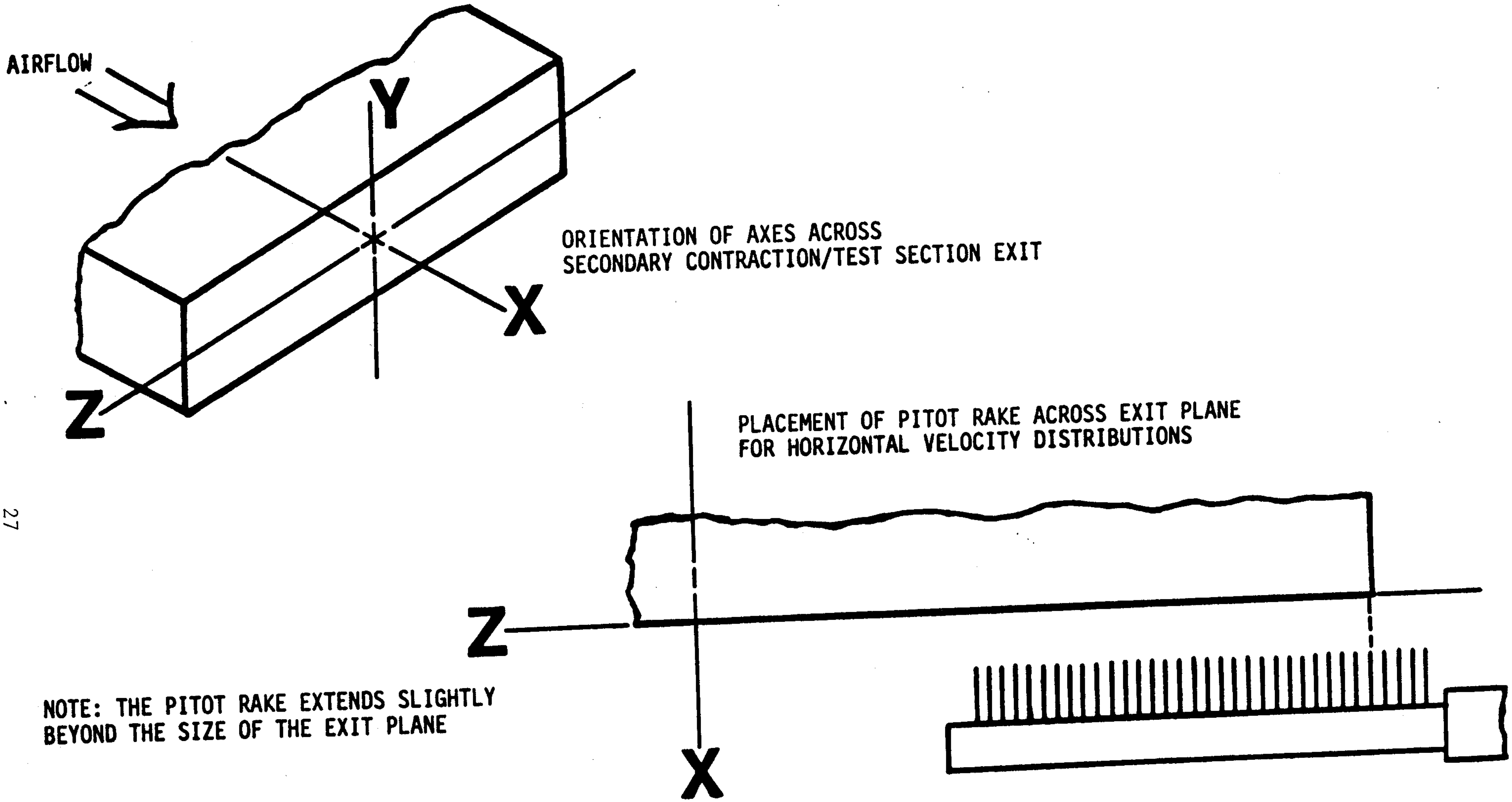
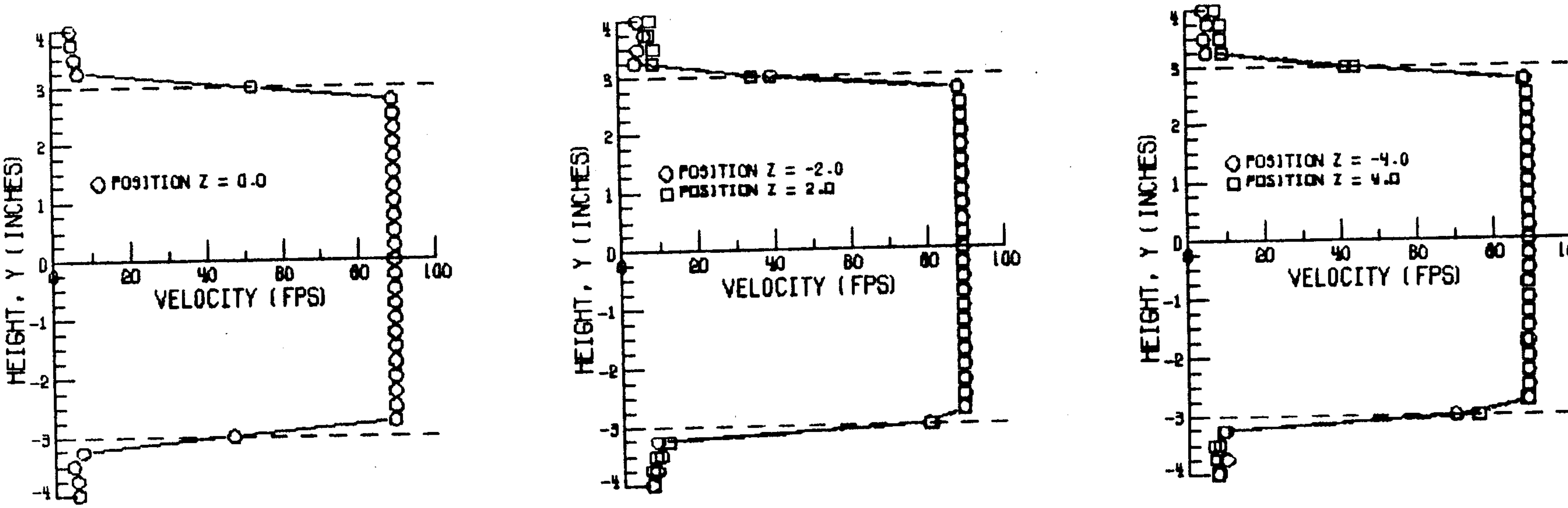


FIGURE 9 - PLACEMENT OF PITOT RAKE ACROSS EXIT OF SECONDARY CONTRACTION/TEST SECTION FOR ACQUISITION OF HORIZONTAL VELOCITY DISTRIBUTIONS



NOTE: Dashed lines indicate tunnel walls.

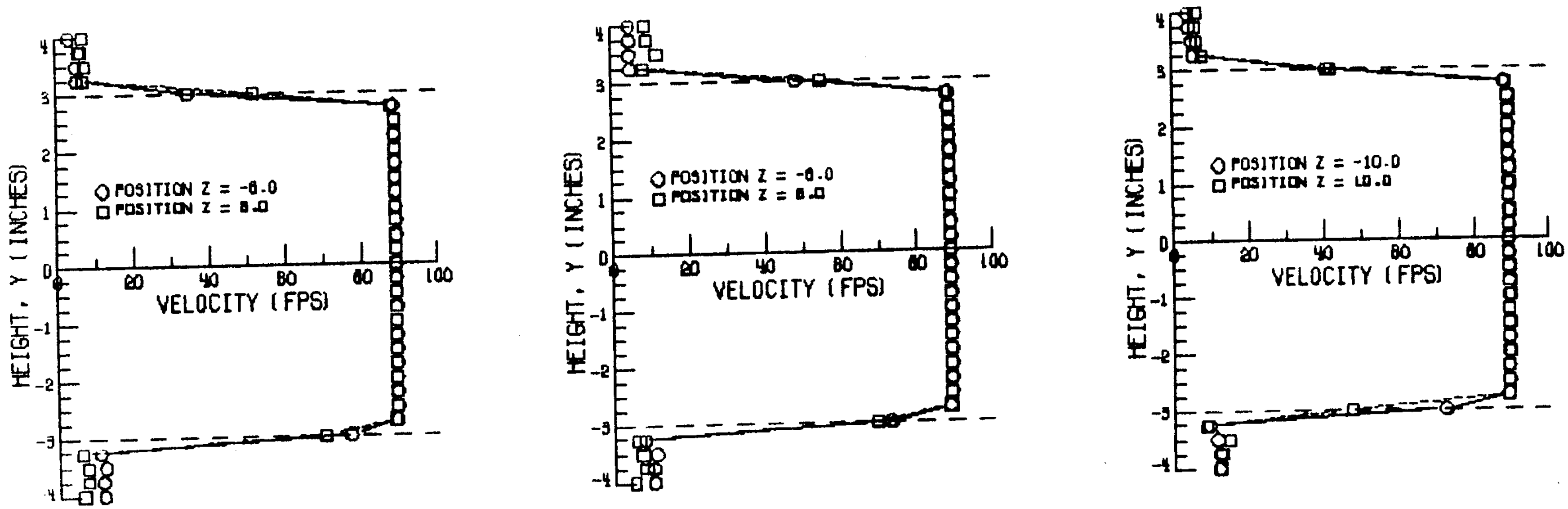
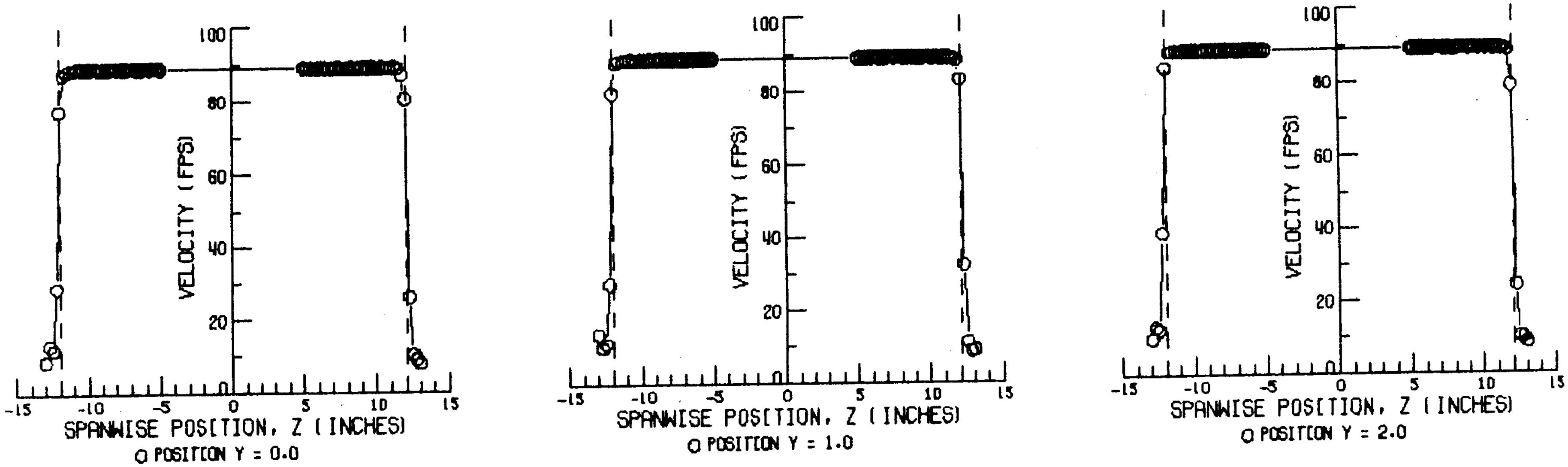


FIGURE 10 - VERTICAL VELOCITY DISTRIBUTIONS AT SECONDARY CONTRACTION EXIT



NOTE: Dashed lines indicate tunnel walls.

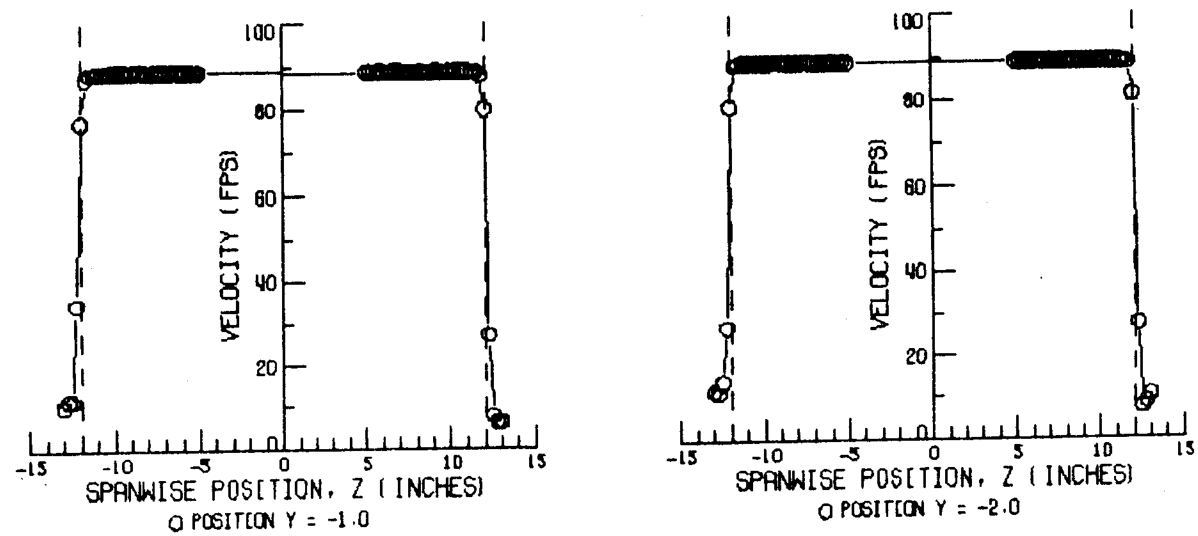
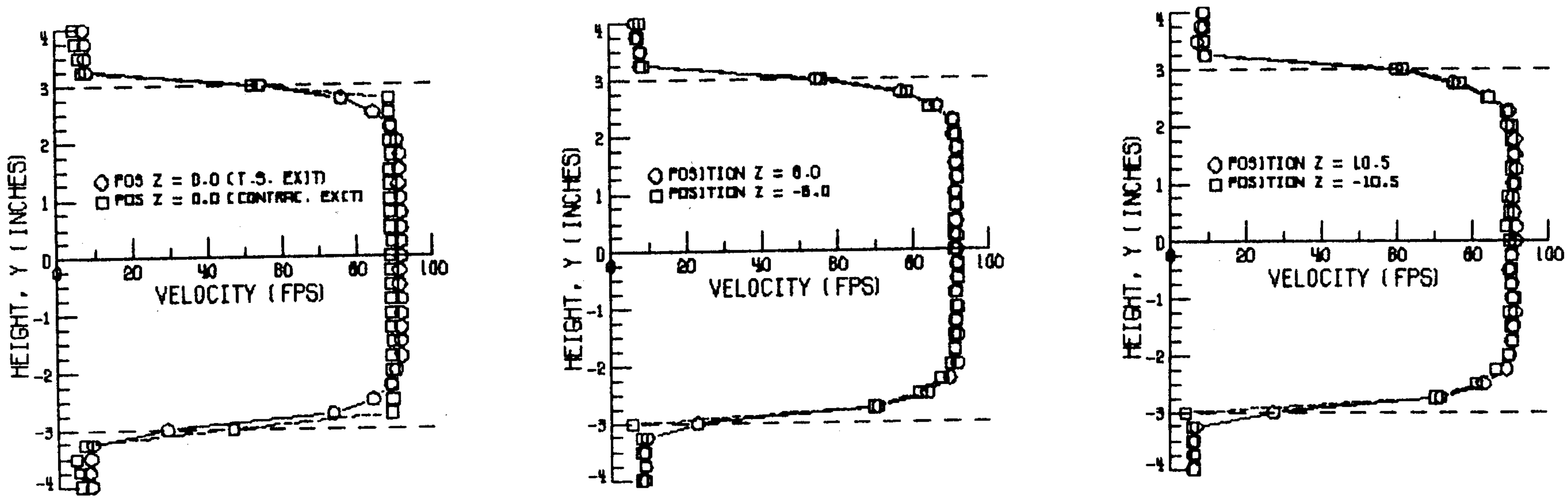
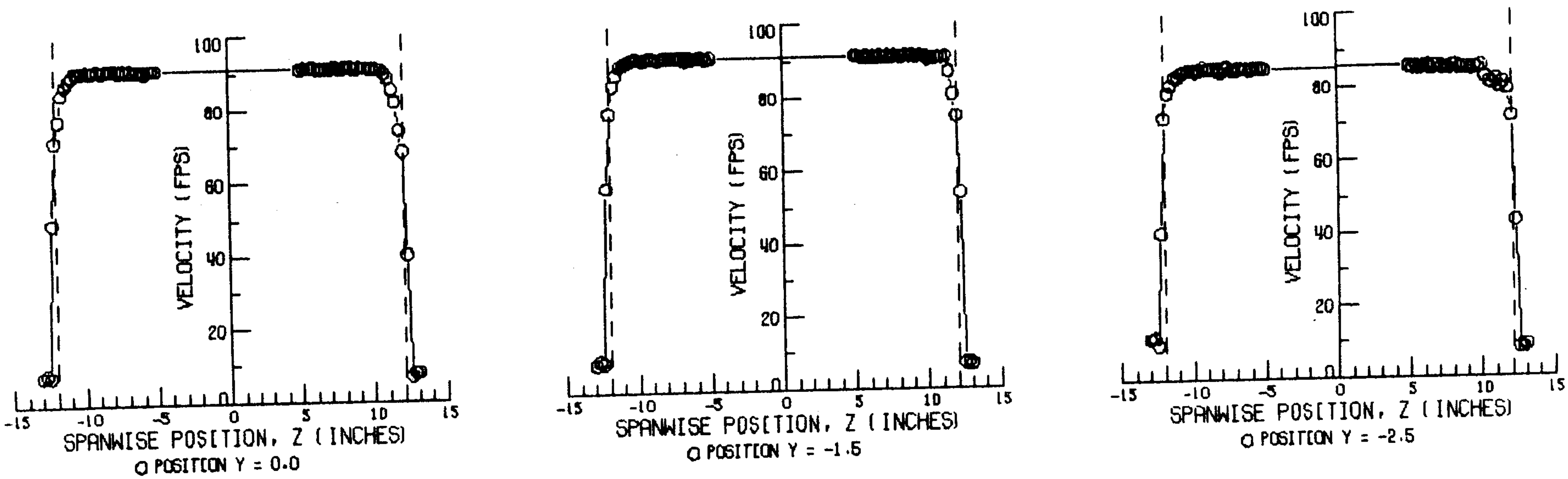


FIGURE 11 - HORIZONTAL VELOCITY DISTRIBUTIONS AT SECONDARY CONTRACTION EXIT



NOTE: Dashed lines indicate tunnel walls.

FIGURE 12 - VERTICAL VELOCITY DISTRIBUTIONS AT TEST SECTION EXIT
(UNCORRECTED FOR BOUNDARY LAYER GROWTH)



NOTE: Dashed lines indicate tunnel walls.

FIGURE 13 - HORIZONTAL VELOCITY DISTRIBUTIONS AT TEST SECTION EXIT
(UNCORRECTED FOR BOUNDARY LAYER GROWTH)

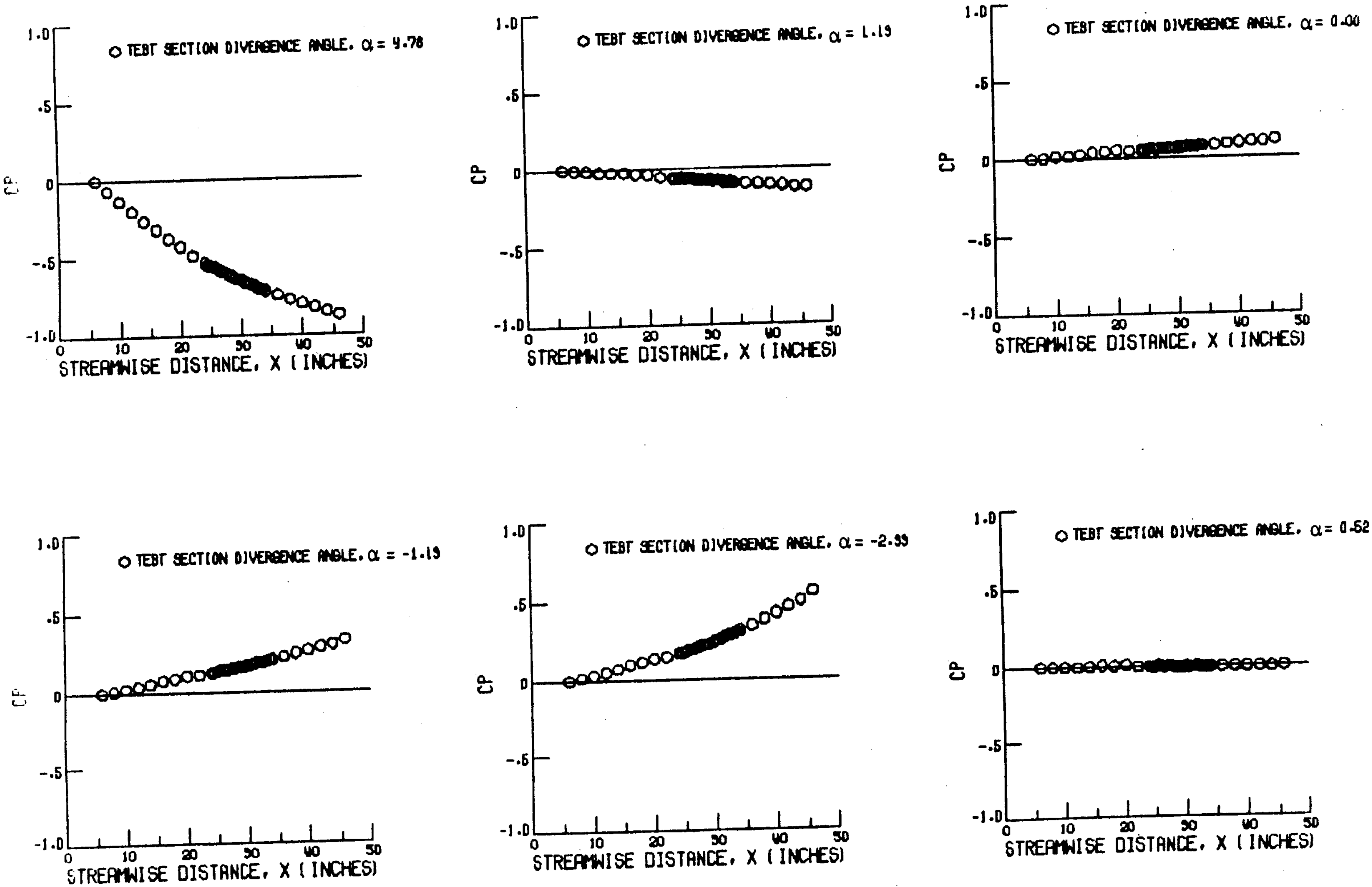
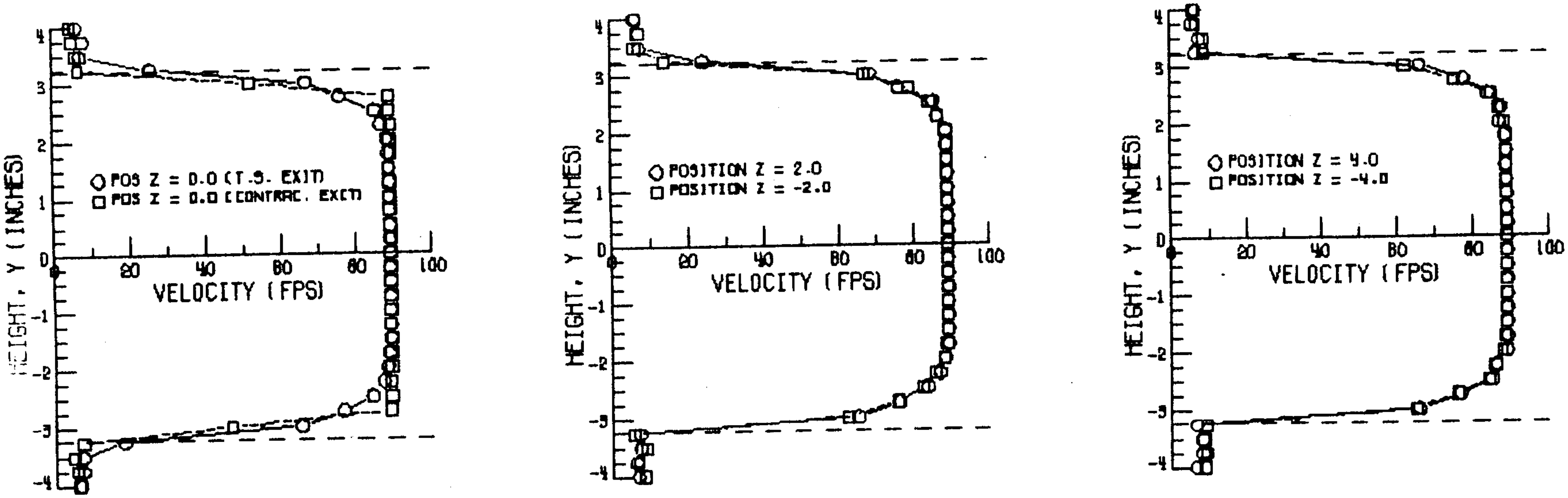


FIGURE 14 - LONGITUDINAL PRESSURE DISTRIBUTIONS IN TEST SECTION



NOTE: Dashed lines indicate tunnel walls.

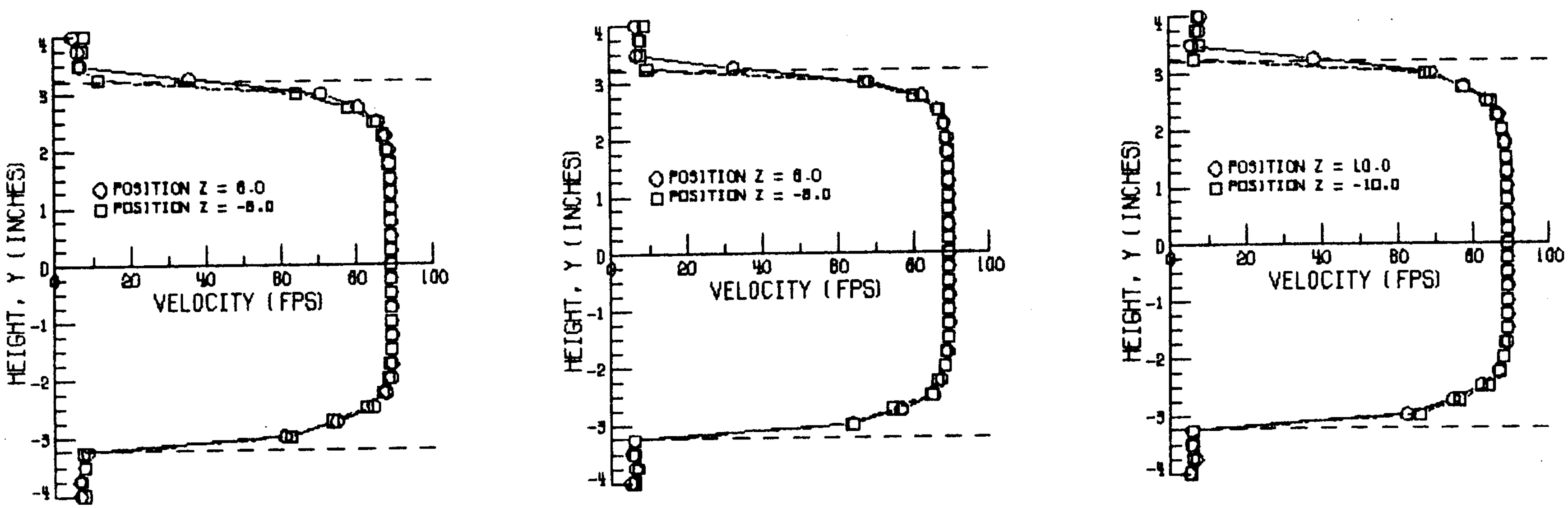
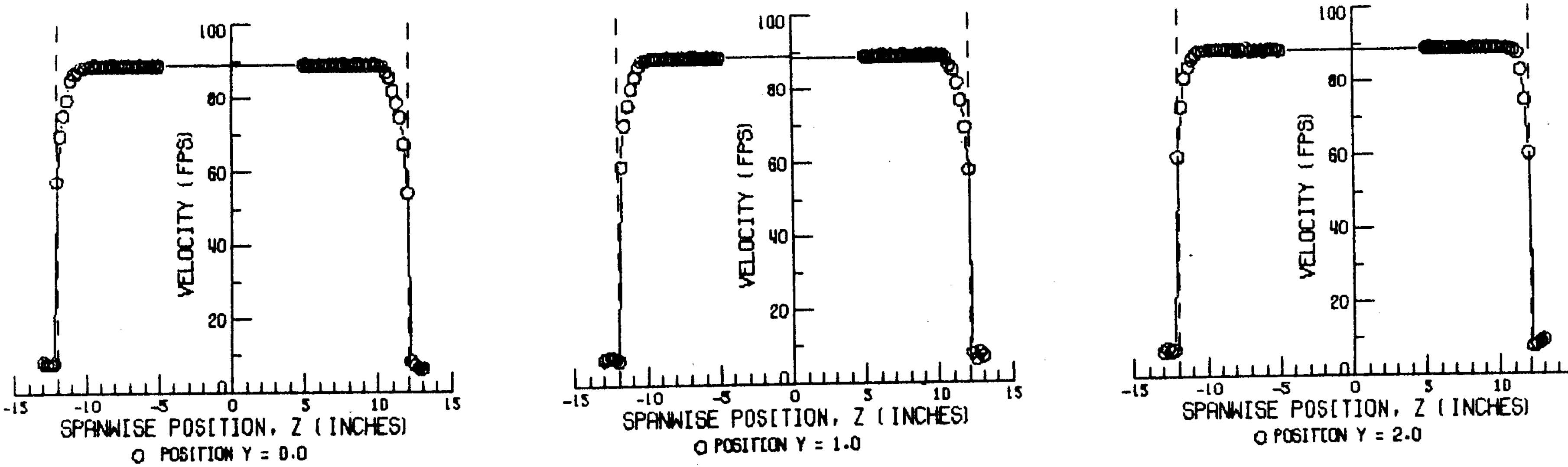


FIGURE 15 - VERTICAL VELOCITY DISTRIBUTIONS AT TEST SECTION EXIT (CORRECTED FOR BOUNDARY LAYER GROWTH)



NOTE: Dashed lines indicate tunnel walls.

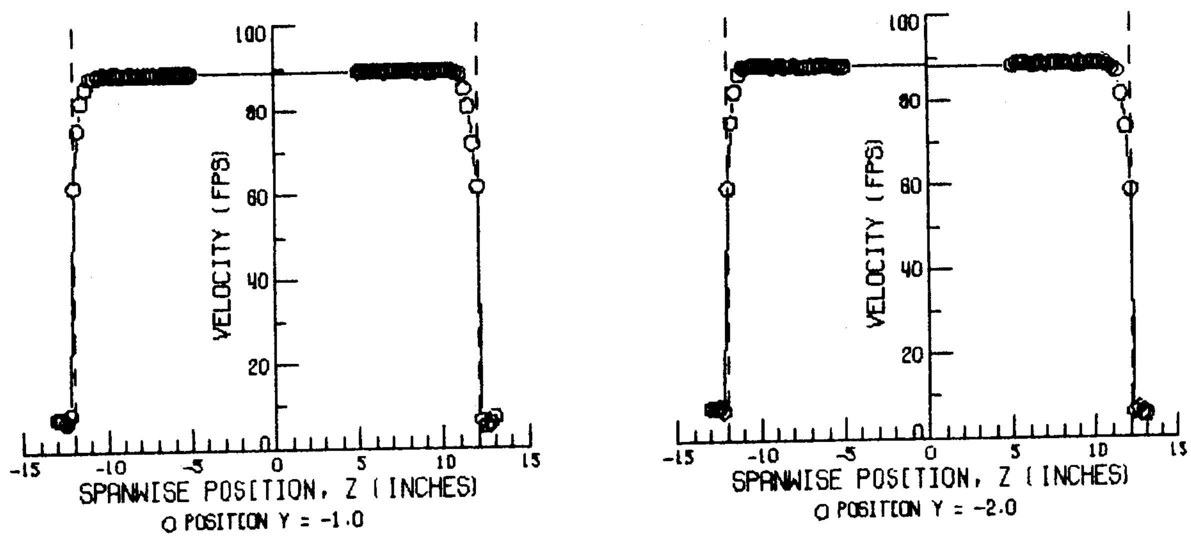


FIGURE 16 - HORIZONTAL VELOCITY DISTRIBUTIONS AT TEST SECTION EXIT
(CORRECTED FOR BOUNDARY LAYER GROWTH)

1. Report No.
NASA CR-178399

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
The Design and Preliminary Calibration of a Boundary-Layer Flow Channel

5. Report Date
October 1987

6. Performing Organization Code

8. Performing Organization Report No.

10. Work Unit No.
505-60-21-02

11. Contract or Grant No.
NAS1-17919/NCCI-24

13. Type of Report and Period Covered
Contractor Report

14. Sponsoring Agency Code

7. Author(s)
Dhanvada M. Rao and Timmy T. Kariya

9. Performing Organization Name and Address
Vigyan Research Associates, Inc.
Hampton, VA 23666 and
George Washington University, Langley Research Center
Hampton, VA 23665

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Langley Research Center
Hampton, VA 23665

15. Supplementary Notes
Dhanvada M. Rao, Vigyan Research Associates, Inc.
Timmy T. Kariya, George Washington University
Technical Monitor, John E. Lamar, Langley Research Center, Hampton, VA

16. Abstract

Design procedures of a new low-speed boundary-layer research channel are described. The channel is an open-circuit wind tunnel for the study of two-dimensional boundary layers under controlled pressure gradients, and follows design guidelines from published literature on blower tunnels with wide-angle diffusers. The contraction was arranged in a modular fashion that permits two different test sections of square and high-aspect-ratio cross sections. A radical type of wide-angle diffuser was employed, and a stream-tube computer code (General Electric Streamtube Curvature Code) was used to check the contraction designs. The alternate test sections have the following specifications: 2- by 2-foot cross section with a fixed velocity of 23 feet per second, and a boundary-layer section with a 0.5- by 2-foot cross section at a fixed velocity of approximately 89 feet per second. Experimental techniques and data are described for the evaluation of diffuser effectiveness, boundary-layer channel characteristics, and overall performance of the facility.

17. Key Words (Suggested by Author(s))
Flow channel design
Boundary-layer channel

18. Distribution Statement
Unclassified - Unlimited
Subject Category 02

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	36	A03

For sale by the National Technical Information Service, Springfield, Virginia 22161